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SOME OBSERVATIONS ON RESILIENCE AND ROBUSTNESS IN HUMAN SYSTEMS

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This article begins with a discussion of robustness versus resilience of a system. Next, I consider two aspects of human societies relevant to explicating human behavior and how each of these relates to robustness and resilience. The argument is exemplified through consideration of hunter–gatherer societies; more specifically, the material and cultural adaptive systems of the Netsilik Inuit, an Arctic hunter–gatherer group. Three structural conflicts in Netsilik society and their resolution through cultural practices are delineated. The relationship between these cultural practices and resilience versus robustness of the social systems is examined. The importance of self-monitoring of the state of a system as part of the system's resilience is discussed, especially with regard to cultural systems that lead to group level benefits.

INTRODUCTION

While driving eastward along Wilshire Boulevard in Los Angeles, California, USA, I observed the very tall, thin-trunked palm trees that border the boulevard. These trees sway gracefully in a wind, returning to their upright posture when the wind dies down. The amount they sway is considerable, depending on the strength of the wind. As I turned off the boulevard to a residential street the palm trees changed to sycamore trees, with heavy, substantial trunks. Even in a heavy wind the sycamore

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tree stands solid, impervious to the force of the wind. Occasionally, one of the sycamore trees that does not bend with the wind might be uprooted by a strong wind, and crash to the ground, but the slim palm trees simply bend and remain standing even in the strongest of winds. The movement of the palm trees and the rustling of the leaves of the sycamore tree are a poetic sight, but on this particular day I did not see poetry in the movement of the trees; rather, I saw a model for resilience and robustness.

In the first part of this commentary, I will set out a definition of robustness versus resilience based on this model, and then I will use the definition to define a resilience index. However, there is no reason to assume that systems are either robust or resilient and the definition makes clear there potentially is a continuum going from robust to resilient. As a consequence, I suggest that not only do we need a measure of robustness versus resilience, but we also need to consider the frequency distribution of the index over a suitable population of systems, as systems may have constraints in terms of how they are realized empirically that may make some range of values of the index more probable than other values.

With this as a background, I turn to human systems and consider, as an example, a group of hunter–gatherers known as the Netsilik who lived along the Hudson Bay in Canada. While hunter–gatherer societies may appear remote from the perspective of western, industrialized societies, they represent the context in which the evolution of *Homo sapiens* took place and were the primary means for resource procurement until the advent of agriculture at about 8,000–10,000 years BP. Because they are small-scale societies, it is easier to delineate their mode of subsistence and how subsistence practices are implemented through cultural means than is the case with large-scale societies.

The Netsilik adaptation to an Arctic environment exemplifies the way in which behavior has both a material and an ideational/cultural dimension. Behavior grounded in material conditions often is found to have optimal or near-optimal configurations that also are relatively stable through time, whereas behavior arising through cultural conditions is complicated by interplay between group-level benefits and individual interests that make stable configurations less likely. Both robustness and resilience play a role in Netsilik adaptation to their physical and cultural environment. Some systems are robust and others are resilient. In addition, for behaviors relating to the interaction of individuals, monitoring of the current state of a system, I conclude, plays a much

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more prominent role than is true for behaviors arising from material conditions due to the greater difficulty of arriving at stable configurations of behavior for the former.

DEFINITION OF ROBUSTNESS VERSUS RESILIENCE

We can think of a tree as a dynamic system in equilibrium with respect to the forces of gravity. Tree growth takes advantage of horizontal symmetry around a vertical axis as a way to distribute gravitational forces so that the downward force due to gravity on one side of the tree is balanced by the downward force of gravity on the other side of the tree. (Sycamore trees are curious, though, for as neat as symmetry may be for balancing gravitational forces, some sycamore trees violate symmetry and do not seem to mind having massive trunks that grow at almost any angle from the vertical trunk. It is, if natural selection insists on having at least one case where symmetry is violated, telling us that the world of nature would be too simple and too predictable if symmetry always ruled.)

When the wind blows, the new force acting on the dynamic system of a tree responding to gravity temporarily shifts its current state, as measured by the tree's position in three-space, to a nonequilibrium configuration, and when the wind dies down the tree returns to its equilibrium configuration, just as models of linear systems with stable equilibrium points indicate how a dynamic system responds to a transient impulse. Let us imagine the tree as being represented by a vertical, straight line, L, when no wind is blowing and when the wind blows, the line changes its angle, with respect to the ground while keeping the coordinate location of the line's intersection with the ground fixed. We can measure the horizontal shift, H, in the top of the tree when subjected to a wind by the length of the arc subtended by the tip of the line, L: $H = L$. We will use the magnitude of H as a measure of the extent to which the state of the tree has changed due to the wind.

What differs between the palm tree and the sycamore tree is the scale for measuring change in the state of the system due to a transient force before system collapse. By scale, I mean the scale (meters, centimeters, millimeters, etc.) for a unit of measurement for which the measurement of interest will have a scalar value between, say, 0 and 10 using that unit of measurement. For the palm tree, the scale will be meters, whereas, for the sycamore tree, the scale will perhaps be centimeters for the trunk and main branches of the tree. We also need to specify over what transient

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states of the system we wish to make a measurement. Here we are interested in a measurement of H for values representing the largest value H may take on before there is system collapse. Let F_M represent the maximum transient force that a system can receive before system collapse. We can use F_M to indicate over what force range an appropriate numerical scale for measuring how the system's response to a transient force, F, should be determined. In the case of trees, the magnitude of F_M is tree specific and if the transient force, F, is such that $F > F_M$, then the tree will crash. For our purposes, we want to know the response of the tree for $0 << F < F_M$; that is, the response over the upper range of forces but below the value, F_M, for which the system will crash.

In contrast with a sycamore tree, the magnitude of H for a palm tree can be measured using a numerical scale commensurate with a scale for measuring the height of the palm tree. This difference between a palm tree and a sycamore tree provides us with an index for differentiating these two systems, using the idea of resilience versus robustness. To do so, let us denote the scale for measuring the magnitude of H by S_H. Now use the same scale, S_H, to measure L. Let us define a dynamic system as *resilient* when $H \sim L$, with both measures based on the scale S_H, and let us define a dynamic system as *robust* when $H \ll L$. Let us call H/L the *Resilience Index* (*RI*) for the dynamic system represented by our tree example. For a palm tree, RI will differ from the index value for a sycamore tree by at least an order of magnitude.

We easily can generalize this example to any dynamic system for which there is a single quantitative scale appropriate for measuring both the state of the system and for measuring the magnitude of the response of the system to a transient force.

FREQUENCY DISTRIBUTION FOR THE RESILIENCE INDEX

Now consider a population of comparable dynamic systems, such as a population made up of a variety of tree species, and consider the frequency distribution of RI measured over the members of that population. *A priori*, we cannot specify the shape of that distribution as we can, in principle, construct a population of dynamic systems for which the frequency distribution of RI can take on any possible shape.

However, it is less clear that nature is without patterning in terms of the values of RI for dynamic systems of a similar kind. When we compare a palm tree to a sycamore tree, we find a substantial difference

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in the value of RI for these two tree species. The difference relates to the fact that the trunks of the two kinds of trees are built up using different organic structures. The trunk of a palm tree is much more fibrous and the trunk of sycamore tree has a much more rigid, cellular structure. The former has evolved (in part) for its ability to bend without breaking and the latter as a way to resist bending without breaking. Pine trees and fir trees are cases somewhere in between a palm and a sycamore tree. Not surprising, perhaps, is the fact that palms, sycamores (and other hardwoods), and pine and firs (and other softwoods) do not form a continuum going from flexible to rigid, but form a mix of trees for which the RI values would have a trimodal frequency distribution. The reason for the trimodal pattern lies in the fact that each kind of tree (fibrous, softwood, and hardwood) represents a distinct solution to the problem of resisting a transient force. Apparently, structures in between these particular solutions that have been "found" by trees through natural selection are less effective in resisting transient forces in conjunction with the other factors affecting the properties of the organic material making up the trunk of a tree.

Thus, while in principle, there is no *a priori* frequency distribution that should characterize the value of RI measured over a population composed of dynamic systems, due to the pragmatics of evolution and adaptation, it is likely that not all values of RI equally are probable and empirically we may well find that the value of RI has a multimodal distribution when measured over comparable dynamic systems. This suggests that the question of robustness or resilience of a dynamic system has both an individual and a group aspect. Any particular system will have some specific RI value, but we would like to know not only the extent to which a particular system is robust or resilient, but the pattern of RI values over comparable systems as a way to determine whether or not possible RI values also are responding to broad constraints on the way a system is constituted.

Now consider what happens with human dynamic systems. For the purposes of this discussion I will limit myself primarily to hunter–gatherer societies as hunting and gathering was the primary means by which human societies survived until the advent of agriculture approximately 8,000–10,000 years ago. (See Adams 1978 for an application of Holling's notion of resilience to early agricultural societies in Mesopotamia; Redman and Kinzig 2003; Redman 2005 for a discussion of resilience theory as it applies to archaeology; and van der Leeuw and Aschan-Leygonie

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2001 for a discussion of resilience as it applies to human society/natural systems interface.) For the purposes of this paper I will only consider the value of RI for the different systems within a hunter–gatherer society and even here, results for RI will be at an ordinal level of comparison.

HUMAN DYNAMIC SYSTEMS

Material Criteria versus Cultural Criteria

I will be concerned with two aspects of human societies in this discussion and how each of these relates to robustness and resilience. The first concerns the manner in which biological systems typically are analyzed, namely in terms of behavior as a response to external conditions, in which the response pattern is directed by information processed in accordance with the implications of evolution driven by natural selection. Within anthropology, this approach has often been called a *material approach* as it places primary emphasis on the material conditions under which individuals in a human society operate. The second aspect is more controversial in terms of the extent to which it also can be accommodated within standard theories of natural selection driven by reproductive fitness (individual and inclusive), and relates to the general topic area referred to as culture, namely, the way in which humans respond to internalized systems of meaning that are shared across societal members. This is sometimes referred to as a *cultural approach* as it is based on shared ideas and concepts, not on external conditions. For example, to use an ongoing and current controversy in the United States, the polarization over abortion does not arise from material conditions but from the meaning associated with the act of abortion. For some individuals in the United States, abortion is tantamount to murder because the condition of being a *person* (as opposed to simply being a biological organism) is assumed to arise at time of conception, and if so, abortion is equivalent to taking the life of a person, hence it is murder. For other individuals, personhood is believed to arise in conjunction with the act of birth, hence under this belief, abortion is not murder, as the biological life that is extinguished is not that of a person. The difference between the two positions cannot be resolved by reference to the biological process of reproduction, as the concept of personhood is not biological, but conceptual. One is not a person for biological reasons, but through common agreement on a criterion that is taken as

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the defining characteristic of what establishes personhood. In the context of American culture, however, there is no single, shared criterion for personhood.

Of these two aspects of human societies, systems that properly can be considered under the rubric of material conditions in conjunction with properties arising through some form of natural selection, are more predictable than cultural systems as one finds empirically that, by and large, humans are quite effective in arriving at adaptive/optimal solutions to whatever material task is at hand. When decision-making is driven primarily by material conditions, optimal or near optimal solutions are not unusual and solutions that have been found are not individual specific. In hunter–gatherer societies, hunters pursue game, for example, in a manner largely as expected based on arguments from optimal foraging theory, and in agricultural societies farmers plant foods in soils that are appropriate for the crops and foods that are being grown, and so on, regardless of the specific individuals involved. With optimal solutions, we expect to find general agreement on what are considered appropriate means of doing tasks in terms of material consequences arising from those tasks. Hence, relatively little time and energy should be spent on obtaining group consensus on the tasks per se when it is the material consequences of doing the task that are of primary importance, thereby leading to optimal or near optimal solutions. For example, the kinds of animals and plant foods to be hunted or gathered, the time and locality for so doing, and the implements to be used for these tasks have more-or-less optimal solutions, and hence, do not require extensive discussion and the like by the participants to decide on how hunting–gathering should be carried out. However, I suggest that optimal solutions for decision-making driven by culturally based considerations are less common, and any solution may depend on decisions made by other participants, hence greater time/energy is likely to be spent on determining how tasks that relate to cultural considerations should be conducted. For culturally based factors such as the social relations among the persons making up a work group, and/or culturally determined rights and obligations relating to individual and group ownership of resources and how these rights and obligations affect both cooperation in performing tasks and in sharing the resources obtained from those tasks, optimal solutions are not as easily obtained and stable solutions are difficult to construct. Consequently, a substantial amount of time is spent on reworking relations among individuals. Social relations almost are

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never stable, as they are highly nonlinear, multiply connected, and subject to multiple interpretations that need not be consistent across group members.

The two extremes of activities relating primarily to material conditions or to cultural context provide a modeling simplification that may not be accurate for actual behaviors. Most activities have both a material and a cultural component. Choice of what animal to pursue may be predictable from optimal foraging theory when hunting is done solely for procuring food and/or other animal resources, but hunting also may be done for nonmaterial reasons as well. Bear hunting by the Ainu of Japan or hunting for eagles by American Indian groups was done for ritual purposes and not because of the likelihood of hunting success when hunting bears or eagles. Seal hunting by the Netsilik Inuit (to be discussed below) also carried with it requirements on the part of the hunter to ensure that the soul of the seal would not be angered so that when it was reincarnated in the form of another seal it would be willing to be killed again. Who participates in a hunting party or a foraging group may be dictated more by cultural considerations of social relations and social obligations than simply by who can work well with whom. And how a successful hunter/forager/farmer/worker is perceived by the group for which one is a member may be dictated more by cultural considerations placed upon how success in resource procurement is perceived by the member of one's social group and less by material considerations, such as rewarding successful hunters/foragers/farmers/workers.

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Resilience and Robustness in a Hunter–Gatherer Society

Resource Procurement: Netsilik Eskimo. Consider as an example the yearly round of the Netsilik, an Inuit group living along the Hudson Bay in Canada. In traditional times before the introduction of rifles and other aspects of Western technology, the Netsilik followed a pattern of resource procurement that involved three main food resources: (1) salmon in the summer, (2) caribou in the fall, and (3) seals in the winter. Spring was a transitional period going from seal hunting to salmon fishing as the season progressed.

Summer salmon fishing was based on small work groups of one or two families distributed over the various tributaries that drained into Hudson Bay. Efficiency was achieved by fishing at locations where the rivers were narrow enough for a small group to build a stone dam across

the river to trap the migrating salmon, with both men and women providing labor; men primarily for building the dam and spearing the salmon with a fish leister and women for gutting the fish and preparing them for storage. Larger groups would have been less efficient as the extra labor was not needed at the locations where the fishing was done and wider sections of the river would have had too much current for building stone dams across the river. Salmon runs were plentiful and the tributaries where one or two families fished for salmon normally provided more salmon than could be used by them. One easily can show that the most efficient way to procure a plentiful, migratory resource such as salmon, given their technological limitations and taking into account the possibility of stochastic variation in the quantity of salmon in a tributary, essentially is the one used by the Netsilik.

Fall caribou hunting took advantage of water barriers such as small lakes. The caribou were needed not only for food, but also for their skins that were used for clothing and tents. The hunting strategy was to force the caribou into the lakes, then to harpoon them from kayaks. Hunting on land would have been inefficient because a herd would disperse once the hunters started to kill the caribou. Killing the caribou while swimming made it easier to approach them as the caribou could not easily escape from a hunter in a kayak and the caribou were fat in the fall and did not sink when killed, or could be kept afloat with an inflated skin bag. For caribou hunting, a larger hunting group was needed than for salmon fishing, with labor split between women and children acting as beaters to force the caribou into the water and the men harpooning the swimming caribou from kayaks. While caribou hunting as practiced by the Netsilik was highly effective, it did have the risk that the migratory pattern of the caribou was unpredictable, and if the caribou did not follow the anticipated route, it would not be obtained, and starvation was a likely outcome.

The Netsilik used an intriguing solution to hunt winter seals that, for most of the time, were underwater. As they are mammals, the seals must breathe and so they maintain breathing holes in the pack ice. From the surface, it is impossible to determine which breathing hole a seal might use, and so the strategy of the Netsilik was to have enough men at seal holes (one hunter per seal hole) to ensure that at least one of the hunters would be at the breathing hole used by a seal. Apparently up to about 20 men were needed to ensure high enough odds of getting enough seals on a regular basis to be able to survive through the winter.

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Optimality of Resource Procurement: Material Conditions. For our purposes here, we may note that the Netsilik methods of food resource procurement and the size of the labor force involved were close to optimal, if not optimal, given the technology available to them. The Netsilik are but one of many examples in which behavior reasonably is predictable when behavior is constrained by the consequences of interacting with the physical world. Or, as van der Leeuw has phrased it, "in the area where one could be relatively 'objective' and rely heavily on the laws of nature, these efforts [to account for patterns of behavior] met with the most success" (van der Leeuw 1984, p. 714). We briefly can sketch out a model for why behavior constrained by the physical world will tend to be close to optimal. The model will take advantage of finding a local maximum using a hill-climbing algorithm.

Assume a utility function, U, defined over the outcomes of some set of actions, where the utility function is defined locally by the persons making up a society, both in terms of the form of a graph of the utility function and what constitutes utility. In some cases, the utility function might be measured over material outputs that accrue from an action such as hunting or gathering, or in other cases, it might refer to the cultural domain and, to say, social relations between individuals created, augmented, or redefined through actions such as food sharing. Unlike economic analysis, which usually presumes utility functions based on material outputs, utility cannot be restricted to the material domain alone, because utility can accrue from transactions even when there is no material output of the actions and the only outputs are the social relations established through the action.

Since the utility accrued from an action may be action specific, denote the utility associated with an action, A, by U_A. Actions take place under some set of conditions that may relate both to the material and the cultural domain. For example, the conditions for the action of hunting can involve material conditions, such as the geographical location, the time period during which the hunting takes place, the number of persons making up a hunting group, and so on. It can also relate to the cultural domain through the kinship relations among the persons making up the hunting group. The latter might be expressed in the form of a matrix showing the kin relationship (as expressed through the society's kinship terminology) of each person to every other person, or it might be expressed in terms of some locally defined summary measure of kinship such as "close kin" or "distant kin," however "close" or "distant" kin might culturally be defined.

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Let $C_A = \{C_{A,i}: i I_A\}$ be the set of conditions relevant to an action A, where I_A is an index set. The set C_A stipulates the relevant conditions for the action A. Actions take place in time, so let $A[t_0, t_1]$ indicate that the action A commences at time t_0 and ends at time t_1. We allow for the fact that the condition(s) under which the action is taking place might change during the time period of the action, hence, $C_{A,i}$ is a function defined over the time interval $[t_0, t_1]$. Correspondingly, let $C_{A,i}(t)$ be the time-specific measure of the actual condition that is realized at time, t, when the action A takes place for each $t\,[t_0, t_1]$. For example, a hunting party might commence 9 a.m. in the morning with four hunters and continue until 4 p.m. in the afternoon, but two of the hunters might leave the hunting party at noon. If $C_{A,i}$ is a measure of the number of hunters in the hunting party, then $C_{A,i}(t) = 4$ for $9 < t < 12$ and $C_{A,i}(t) = 2$ for $12 < t < 16$. Finally, let $O(A[t_0, t_1])$ be the return achieved from the action A taking place over the time period $[t_0, t_1]$ under conditions specified by $\{C_{A,i}(t): i I_A, t\,[t_0, t_1]\}$ and over which the utility function, U_A, is defined. As noted above, the return may be material or it may be conceptual and, in either case, it is the "output" of the action to which utility is assigned by the persons in the group engaged in the action A. For example, the output of concern may be the degree of conflict that arises from sharing meat and the utility function may measure the extent to which either argument or rancor arises from meat sharing perceived by some individuals to be less than what they consider to be equitable.

While it obviously is simpler to define outputs as material outputs as is done with economic analyses and to assume utility monotonically increases with the quantity of the output obtained, the utilities brought into play by individuals in a society are not so simply delineated. For example, as we will see with the Netsilik Inuit, two utilities seem to be of particular concern with winter seal hunting. One relates to material outputs and the other to social relations. The former is the positive utility assigned to the amount of seal meat obtained in a hunting episode since seal meat is the sole source of food during the winter. The latter refers to the utility assigned to resolving tensions within the group living together during the winter for the purposes of seal hunting because the ability of the group to continue as a cooperating group depends on resolving conflicts before they escalate out of control. Or, for a case where utilities do not monotonically increase with material outputs, consider the publicly acknowledged utility assigned by the !Kung San (a hunter–gatherer group living in the Kalahari Desert in Botswana) to the size of the animal that

has been killed. With larger animals, the public response is to denigrate the hunter's success or the quality of his kill. The publicly expressed utility thus decreases with the size of the animal, apparently as a way to minimize the possibility of a better hunter exploiting his hunting prowess as a means of gaining power or control over others through his hunting ability and successes.

We can now relate this model of utility to a hill-climbing algorithm for finding at least local maxima for a surface given by a function f defined over some region R R^n, where n is the dimensionality of the space over which the surface is defined. The algorithm can be defined as follows. Identify a point r R as a starting point. Now, select a point r' randomly in a neighborhood, N, of r. If $f(r') > f(r)$, set r' to be the starting point. Otherwise, keep r as the starting point. Repeat the algorithm until suitable convergence conditions are met.

The effectiveness of a hill-climbing algorithm in finding a global and not just a local maximum relates, in part, to the "size" of the neighborhood N in comparison to the distance in R^n between local maxima for the surface f. For surfaces in which the "valleys" between local maxima are small in comparison to the size of N and for surfaces that are sufficiently smooth, the hill-climbing algorithm provides a way to find a global maximum by tracing a path from a starting point to the global maximum based on local variation in the surface. In order to increase the likelihood that the hill-climbing algorithm finds a global maximum rather than a local maximum, one can begin with different starting points, or a point r' can be selected from a neighborhood larger than the neighborhood N for the current starting point, r.

We can incorporate the hill-climbing algorithm in our model of a utility function, U_A, associated with an activity, A, under conditions, C_A, by noting that not all individuals will do an activity A under precisely the same conditions, $C_A[t_0, t_1]$, at exactly the same time. Consequently, we can assume that when the individuals in some set of persons do the action A over comparable time frames (such as the same day or the same week), we have, in effect, a sample of outputs for the activity A under different conditions. Assuming that individuals communicate with one another, each person can consider her or his current set of conditions as a starting point for the hill-climbing algorithm and the action of the other persons as sample points from the space of conditions under which the activity A may be performed. Each person need not be aware of the actions of all other persons; all that is needed is that any one person be aware of the

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action and output for the activity *A* conducted by some other persons in a neighborhood of one's starting point. We will assume that when an individual is aware of another person who has outputs with greater utility, the individual will shift to the conditions used by the other person for doing activity *A*. From the viewpoint of the person considered to be the focal person for this process, the other persons for whom the focal person is aware of their actions and outputs provide the sample points in the neighborhood of the focal person's starting point. For output surfaces and utility surfaces that are reasonably smooth, the strategy of shifting to the conditions utilized by a person in the neighborhood of the focal person's current starting point will converge to a global maximum with regard to the utility surface measured over the outputs from the various conditions under which the activity, *A*, may be performed.

It should be noted that the size of a neighborhood, or alternatively, the set of persons for whom one has information about conditions under which an activity *A* occurred and with what output, is critical. In particular, it is disadvantageous for arriving at a global maximum to be knowledgeable of the actions and outcomes of all other persons, for if each person has access to information about all other persons at a given step in the process, then on the next step, all persons would do the activity using the same conditions as the person who had the greatest output on the previous step and the process would stop—unless the outputs also are dependent on the number of persons doing activity *A*. If the outputs are dependent on the number of persons doing activity *A*, and if the outputs decrease below the amount obtained on the previous step with persons doing *A* under different conditions, then oscillatory behavior could arise, because on the second step, each person would receive less output than on the first step, and so should shift back to the conditions used for doing *A* on the previous step. In effect, incomplete information and/or individual variation in doing the same action ensures that at each step there is sampling of conditions around the starting point of each individual, a critical feature of a hill-climbing algorithm.

Unlike Darwinian evolutionary models based on external selection of behaviors with greater relative fitness through the consequences of those behaviors vis-à-vis fitness, and hence operating on a time frame of generations for change in behaviors, humans are capable of evaluating the current set of conditions and outputs against a utility function, can compare these outputs and utility accrued against the set of conditions and outputs achieved by other individuals, and make decisions accordingly

on a relatively short time frame. Darwinian models of evolutionary change also are based on situations in which the mechanism for the transmittal of behavior (viewed as part of the phenotype of an individual) is not under the control of the individual. In contrast, the model outlined here takes advantage of the fact that humans have both the capacity to evaluate one's current state of affairs vis-à-vis the state of affairs of others and to modify one's behavior in accordance with that evaluation.

While it might be tempting to summarize the model being used here as "Imitate the most successful individual," this prescription would leave unanswered what constitutes "the most successful individual." Darwinian evolution assumes individual (relative) fitness is the measure for the "most successful individual." However, the model outlined here does not depend on fitness as the driving force for shift in behavior, but only on individual evaluation of one's outputs and utility accrued from those outputs against outputs and utilities accrued by other individuals. Because utilities are context specific, "successful" cannot be defined universally and needs to be determined with regard to the cultural and material conditions under which actions are taking place. More precisely, more "successful" essentially means doing an action A along a path leading to a global maximum via the hill-climbing process that is closer (as measured along the path leading to a global maximum) to the location of the global maximum than other instances of the activity A being done by other persons. Thus, a shift in behavior towards an adaptive/optimal behavior does not require differentiation among behaviors in terms of reproductive fitness as required by Darwinian evolution; rather, it only requires differentiation in behavior in terms of the utility for which a particular behavior is defined as adaptive/optimal.

It also should be noted that the evaluation of utility involves not only the specific conditions under which an activity A may occur, but also the set of conditions C_A and even the activity A. Humans also are capable of innovation and can change purposefully the structure within which actions and decisions about actions are embedded—that is, they can both change the activities A and the conditions C_A for doing the activities. Innovation in Darwinian evolution is outside of the evolutionary process driven by fitness through the variability in, and the inheritance of, traits and is relegated to external random mutation. Humans, however, are quite capable of modifying the current structure within which they operate, although there are clearly constraints—even if not yet well understood—that affect the degree of, and the direction in which, change

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can take place. Thus, models that limit the transmittal of behavior patterns to criteria such as "imitate the most successful individual" or "imitate the most common action" are too restrictive, though their advantage over Darwinian models of behavior transmittal based on relative fitness alone are evident.

Utilities based on material outputs related primarily to material conditions for doing an action are more amenable to change aimed at the maximization of utility because it generally is easier to modify the material conditions under which activities take place than the cultural conditions that may be involved. Conditions such as the kin relations of persons making up a work group, sharing of resources based on group versus individual ownership, rights and duties accruing through group membership, and so on, may be culturally expressed, and hence shared by all or most of the members of one's society, thus making change in those conditions dependent upon group consensus for any proposed change. In contrast, changes in the material conditions under which an activity occurs may only involve the person(s) directly involved in the activity, hence, they are more amenable to individually motivated change. Thus, we can expect that when utilities relate to material outputs of activities, activities will occur under conditions that are likely to be close to optimal for individuals, whereas when utilities relate to the cultural domain, the relationship between activities as they actually occur and optimal activities defined in terms of utility maximization at the individual level are likely to be more divergent from actual behavior.

An example of the facility with which behavior based on material conditions can change is seen with the introduction of rifles to the Netsilik. Rifles drastically changed the dynamics of hunting and the traditional means for procuring food resources were modified accordingly in a very short period of time as the rifle made hunters far less dependent on others for hunting success. With the introduction of rifles, a single male could kill caribou easily and the need for forming caribou hunting groups disappeared. Seals could be shot in open water and did not have to be harpooned at breathing holes. Within a few years, traditional modes of hunting largely disappeared with long terms consequences for the social organization of the Netsilik, as much of that organization had developed around ensuring the kinds of hunting groups needed effectively to hunt caribou and seal. Whereas hunting methods could change quickly with the introduction of rifles, consequences for the social "fabric" of the Inuit, implications for their cultural identity, and

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ways to adjust their ideational framework to take into account these changes do not change as rapidly, and adjustments take place over far longer time periods. In many ways, their cultural framework has not been able to deal with a rapidly changing set of material conditions initiated through interaction with western peoples.

Cultural Framework and Material Conditions

We now consider the relationships between the material and the cultural conditions of the Netsilik with regard to their traditional way of hunting and living. We begin by characterizing the material model for the Netsilik as indicated in the left side of Figure 1. What we will show is that there were three main structural conflicts that arose in Netsilik society. The first relates to optimization with respect to material conditions. The second arises as a consequence of the cultural means for implementing a solution to the first structural conflict, and the third arises out of the solution found for the second structural conflict. Taken together, the three solutions made for a resilient system in which parts of the system could be modified in response to transient forces on the systems and

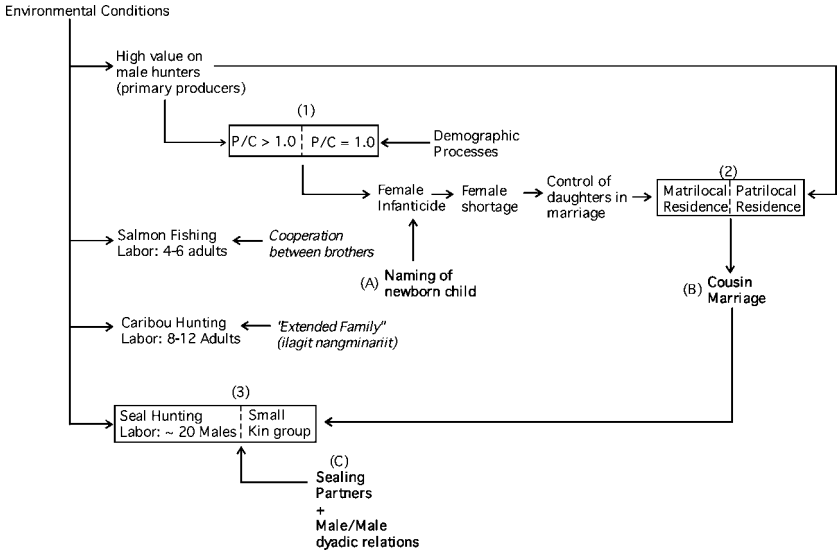

Figure 1. Netsilik adaptation and cultural practices. Boxes identify potential structural conflicts. Bold indicates cultural practices that resolve a potential structural conflict.

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for which return to "equilibrium conditions" would occur once the transient forces had abated.

By bending like the palm trees in a strong wind, the Netsilik were able to survive for centuries in one of the harshest environments in which humans have existed. In contrast, English explorers looking for the Northwest passage starved to death in their ships when caught in the Arctic ice despite the attempts to make the ships, like the sycamore tree, a robust system that would be impervious to the external transient forces of an Arctic winter. The Arctic winter exceeded the F_M for the exploratory ships and their crews perished while the Netsilik, with their resilient system and living in the same area, survived from one year to the next. Similarly, when the Inuit reached Greenland and intersected with the Norse living on the southwestern coast of Greenland, the Inuit with their resilient system were able to survive a change in climate towards colder and worsening conditions, whereas the Norse colonists had to retreat from Greenland as their system of adaptation did not have the resilience needed to deal with a worsening climatic condition.

The environmental conditions of the Arctic limited food resources to hunting done primarily, if not exclusively, by males; hence, a high value was placed on males as the primary producers of resources. Females played a minor role in food procurement and instead their role could be better summarized as the managers of resources obtained by males. Females were responsible for preparing salmon for storage, for making clothing and tents from caribou skin, and for distribution of seal meat to other families during winter hunting of seals. In terms of work groups, salmon fishing could be efficiently done with around four to six adults. Caribou hunting needed around 8–12 adults (and children could be used for scaring the caribou into a lake) and finally, seal hunting depended on having around 15–20 males located at seal breathing holes in the arctic ice. What we want to consider is both the implications of the material conditions on cultural practices and how cultural practices were constituted in order to ensure that work groups of the required size could be realized from one year to the next, despite variability occurring both in environmental conditions and with regard to demographic and social relations; that is, the means by which cultural practices ensured that the Netsilik had a resilient food procurement system.

While the environmental conditions, kinds of resources, and distribution patterns of those resources determine what would be an optimal means for procuring resources, and while the Netsilik appear to have

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been operating at optimal or close-to-optimal strategies for resource procurement, missing in the material argument is the means by which the appropriate size of a group, which differed in the summer, fall, and winter, could be assembled. It is here where the question of resilience versus robustness and the relationship of resilience and robustness to cultural practice becomes important. Briefly, the problem faced by the Netsilik is that cooperation in the sharing of resources without cultural rules for the sharing of foods depends on sharing among close-kin relations. But kin relations, as they occur in human societies, are cultural constructions (Read 2001) and the size of one's kin group depends on one's cultural construction of who constitute close kin, with kin determined through reproduction, marriage, and other means by which kin are established, including adoption.

Among the Inuit, being a parent from a kinship viewpoint is not simply a consequence of a male providing sperm and a female providing an ovum. Rather, it is that and more. The "more" relates to the role of adoption and the lack of distinction the Inuit make between one's genealogical relatives and relations by adoption. Adoption is important for the Inuit because of a practice of female infanticide, apparently motivated by an attempt to increase the ratio of hunters to consumers in a residential group. Adoption was the means by which a family with enough sons and wanting a daughter might obtain a daughter by adopting a newborn girl otherwise abandoned at birth. While the hunter-to-total-consumer ratio relates to the likelihood of a residential group having adequate food resources, the full range of activities needed for survival in the Arctic required complementarity between male tasks and female tasks. Whereas men were the providers, women were the managers once the men obtained resources (food, skins, etc.). And daughters, through marriage, provided a secondary means by which the number of hunters could be increased if the newly married couple remained in her camp. Thus, depending on stochastic events affecting the relative number of sons and daughters a couple might have, some families would see it in their interest to attempt to increase the ratio of hunters to consumers whereas other families may see it in their interest to increase the number of daughters for the benefits accrued through the marriage of daughters.

Structural Conflict 1: Demographic Processes versus an Optimal Producer/Consumer Ratio. From a robustness/resilience viewpoint, we may note that changing the Producer/Consumer (P/C) ratio to a

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value >1.0 would make the resource procurement system more robust for the state of the procurement system measured in terms of calories obtained per day per consumer. With a greater number of producers, more variability in resource availability (transient effects) could be accommodated before there would be food shortages that could lead to starvation, because a successful hunter of caribou or seal, for example, provides enough for his family's needs and for several other persons as well. With a high P/C ratio the food/day/consumer is less dependent upon all the hunters being successful hunters.

This leads to the first structural conflict (see box labeled (1) in Figure 1) the Netsilik had to address, namely, the biological facts of reproduction and its implication for family structure versus the family structure that would provide greater robustness against stochastic variation in resource availability. The time period that elapses between when there is a new consumer and when there is a new producer of resources relates to the magnitude of the cost a group must be able to accommodate when a birth takes place. From the viewpoint of a family as a resource procurement unit, it would be desirable to have at least the first born child be a male since a first-born daughter increases the time period for which there is an increase in the number of consumers without an increase in the number of producers, hence placing the family at greater risk with respect to stochastic variation in resource procurement. The "solution" from a material viewpoint would be to practice infanticide against at least the first-born child if she is a daughter in order to increase the odds that the oldest child in a family is a male. In addition, if the goal is to increase the P/C ratio, the total number of pregnancies desired by a family must include any daughter lost to infanticide; otherwise the effect would be to increase the number of families with a first-born child as a male, but the overall sex ratio, hence the P/C ratio, would not be affected. That a family's strategy was centered around increasing the P/C ratio is born out by census data from when traditional modes of hunting were still being practiced that show a male/female ratio of about 1.5:1.0.

The means for changing the P/C ratio is straightforward, even if cruel from a Western perspective: infanticide is practiced on newborn females. The problem faced by the Netsilik—and by any group that attempts to reduce the fertility that otherwise would ensue from normal sexual activity of adults—was to legitimize a means for preventing each and every pregnancy from becoming a newborn to be cared for and fed.

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Whether it is via sexual abstinence, abortion, or infanticide, human societies seem to require cultural legitimization for behavior that runs counter to maximization of individual fitness. For the Netsilik, legitimization of infanticide was achieved through a cultural definition that personhood did not accrue to a developing organism until it has been named. The mother who has just given birth names her offspring for one of the spirits that helped her during childbirth, hence infanticide in the form of abandoning a newborn that has not yet been named was not considered murder (see cultural practice labeled (A) in Figure 1). An abandoned child could be adopted, and for the adopting family, by providing the newborn with a name, they, in effect, gave the newborn its personhood and thereby became its parents. As a consequence, the Netsilik, like other Inuit groups, do not distinguish between biological children and children obtained through adoption. In effect, through a culturally constructed naming practice, the Netsilik provided a "window of opportunity" during which infanticide could occur without it being considered "murder."

If we view the family and its ability to procure needed resources the dynamic system, then the "equilibrium" value from the viewpoint of the adults in the family would be having a number of children (taking into account their sexes and ages) for which one was able to provide sufficient food resources throughout the year. A "shock" would be a pregnancy, as this will increase the number of consumers. One way to return to equilibrium would be through determining that the family could obtain sufficient resources for another child and thus deciding to keep the newborn, even if it is a girl. Alternatively, the family could return to an equilibrium state through infanticide. Unlike the palm tree or sycamore tree that has no control over the shock to the system in the form of wind and must wait for the wind to die down to return to equilibrium, the Netsilik family has the option of removing the shock, hence, control the time frame for the return to equilibrium. Is this a robust or a resilient system? If we take the system state, F, to be, say, the average number of calories per consumer in the family, then from the viewpoint of a family that decides to keep the child, the system, in the form of a family's means for resource procurement, is robust and $F < F_M$, because the additional child is perceived as having only a small, long-term effect on the average calories per person in the family. From the perspective of a family that decides upon infanticide, the family's food procurement system also is robust, but the additional child is seen as having a significant effect on

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the family's ability to have sufficient food resources, as implied by the decision to practice infanticide. That is, $F > F_M$. By practicing infanticide, the family is, in effect, removing a "shock" greater than can be accommodated by the family's food procurement system.

Structural Conflict 2: Shortage of Females and Marital Residence. Female infanticide had long-range implications, not only for the P/C ratio, but also for arranging marriages for sons and daughters. Female infanticide leads to a shortage of females available for marriage, hence, placing families with marriageable daughters in an advantageous position with regard to the conditions that would ensue after marriage. More precisely, all other things being equal, we would expect that the bride's family would negotiate for the newly married couple to live in the camp of the bride's parents (matrilocal residence) after marriage, as this would increase the P/C ratio for the camp in which the bride's parents reside. However, the groom's family places a high utility on a son as a hunter and, from their perspective, they would negotiate for the newly married couple living with the groom's family after marriage. The two sets of interests are opposed (see box labeled (2) in Figure 1) and, hence, there would be a potential point of conflict that would have to be resolved on a case-by-case basis unless one has culturally specified marriage rules that resolve the potential conflict between the two families involved in the marriage. The cultural rule worked out by the Netsilik is one of cousin marriage (see cultural practice labeled (B) in Figure 1). With cousin marriage, it was possible to both have patrilocal residence (the likely form of residence when residence groups are based on father/son ties as was true of the Netsilik) and for the bride's parents to gain a producer through the marriage.

Residence groups based on patrilocal residence imply that the residence group is structured around father/son ties. Marriage with a cousin would be with a person already in one's residence group in the case of cousins related through the two respective fathers, who are also brothers. For cousins where the parental sibling tie is between a brother and a sister, she may already be a residence in her brother's camp, depending on the type of cousin that she married. Lastly, for cousins in which the parental sibling tie is between sisters, and so their respective husbands need not come from the same residence group, the husbands had a special relationship called *angayungoq-nukangor*, and, due to this relation, they may, in fact, reside together. In effect, cousin marriage with patrilocal residence had the consequence that the newly married bride and groom

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were already from the same camp, or at worst, were from camps with close kin ties, hence, this satisfied the concerns of both families with regard to wanting a son or a son-in-law as a hunter.

Structural Conflict 3: Limited Kin Networks Due to Cousin Marriage. Cousin marriage, however, had implications for the breadth of the kinship network of families. Marriages between offspring already closely related as cousins implied that marriage kept kinship networks restricted to a few families. For most food procurement, this was not a problem. Salmon fishing only needed two or three families working together and typically would involve brothers. Caribou hunting required a larger work group and the personnel needed for caribou hunting could be provided through the residence group based on fathers and sons (a group culturally identified by the Netsilik by the term *ilagiit nangmiariit* ("own relatives in proper," see left side of Figure 1). Seal hunting, however, required a much larger group of males than could be provided through a set of close kin (see box labeled (3) in Figure 1).

The problem faced by the Netsilik (and faced by other groups as well) was the difficulty in ensuring cooperation by families under extreme conditions, in which lack of close kin relations meant that one family had few or no means of coercion to ensure that other families would share resources in an equitable manner. Close kin relations, it should be noted, need not be biologically close kin; rather, kinship and closeness of kin is determined through a culturally constructed system of kinship calculation based on what anthropologists call a kinship terminology, namely, the terms the members of a group use for indicating the kind of kin relationship one person has to another. The kinship terminology is a cultural construct based on a "grammar" for how a conceptual structure with the structural features of a terminology, such as the kin relations of one person to another, being translatable into the kin relations of a third person to the first two persons (Read 2001; Read and Behrens 1990). That is, and using the American Kinship Terminology as an example, if *B* is, say, the Brother of *A*, and *C* is related to *B* as, say, the Uncle of *B*, then the relationship of *C* to *A* (in this case, Uncle) can be calculated from knowing the relationship of *A* to *B* and the relationship of *C* to *B*.

The problem faced by the Netsilik with regard to strangers is well expressed by what an informant told the explorer Rasmussen in 1931:

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> When they broke camp in his grandfather's day . . . the snow knife was never released from the hand . . . A man in the procession could not stop to make water without great risk, for the one who walked in front might easily get the idea that that man for some reason or other would strike him down from behind, and this suspicion alone might be a sufficient cause of bloodshed . . . . So it is no wonder that they were doubly cautious when meeting strangers. (Rasmussen 1931, as quoted in Balikci 1970)

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Strangers in groups such as the Netsilik are individuals with whom one does not have a kin relation. The Netsilik solved the problem of how to ensure that the men making up the work group for winter sealing be close relations of one another (despite a marriage system that acted against having a large group of close kin) by constructing a system of sealing partners that defined how each pair of males in the hunting group are related to each other via the part of seals that would be shared by a hunter with his sealing partners (see cultural practice labeled (C) in Figure 1). The sealing partners had been established by the man's mother at the time of his birth and could be inherited from his father. Selection of sealing partners was for males who were not already close relatives of the male child. Of these 12 partners, six were flexible in that other males could temporarily take the place of one of these partners, depending on the circumstances of how winter seal hunting groups were being formed.

The utility being maximized via the sealing partners is not by the quantity of seal meat, but by an equitable and non-contentious access to a resource obtained through chance, and for which no single person is likely to obtain a sufficient amount, on average, based on his efforts alone. The Netsilik method for equitable distribution was to place the hunter in the position of being the conduit through which the seal is obtained (the hunter stands quietly for hours in the cold of the Arctic winter at a sealing hole) but to remove him from the picture once he has killed a seal. The seal is divided by his wife using a set pattern for the butchering of a seal and the parts of the seal go to the wives of his sealing partners according to the sealing partners established for him by his mother at the time of his birth.

Temporary arrangements also are made each winter regarding the families who have decided to live together for seal hunting and the means for doing so is through half of the sealing partners being treated as

positions that can be temporarily filled by males other than one's permanent sealing partners. In this way, all families know in advance both the conditions under which sharing takes place—namely, any seal that is killed will be shared with the sealing partners of the hunter and only those persons have a right to a portion of the seal—and the amount that can be expected when a seal is killed. The amount corresponds to the kind of partnership a man has with the hunter. In addition to the sealing partners, the Netsilik also had several dyadic relations among males, all apparently aimed at ensuring means to resolve potential conflicts among individuals who do not have close kin relations to one another. These culturally defined dyadic relations, include pairing off of males according to size, "song partners" between unrelated males, and wife exchange.

RESILIENCE AND ROBUSTNESS THROUGH SYSTEM MONITORING

The system of sealing partners made possible the cooperation that was required for a group to survive through the Arctic winter. From the viewpoint of the particular males residing in a winter sealing camp, the system was resilient as it could accommodate "shocks" in the form of events that prevented the same males from living together in the same sealing camp each year. Like the palm tree bending in the wind, the system could accommodate other demands that might affect which sealing camp a man and his family might join from one winter to the next. And like the palm tree returning to equilibrium once the transient force ended, the system of sealing partners would revert back to the permanent sealing partners in future years. Yet from the viewpoint of the amount of seal meat/day/consumer, the sealing camp relatively was robust as the number of hunters was large enough to ensure that, most of the time, adequate seal meat would be obtained through the strategy of placing males at the breathing holes of the seals.

Resilience in terms of having the means to vary the personnel making up the winter sealing camp appears to have been a deliberate strategy aimed at ensuring robustness in terms of food availability per consumer. Robustness with respect to food needs of individuals depended on a system of sharing that ensured each person had equal probability of access to a resource, especially when access to a resource was stochastic with respect to the likelihood of hunting success, and the resource came in a single, large bundle that required some system of distribution that

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had to transcend the individual interests of a hunter with regard to the distribution of his kill. While a system of reciprocity was obviously necessary for the system to work, the Netsilik also realized that one could not depend on individual self-interest to ensure that equitable sharing of a seal would take place, especially when the cooperation is needed among individuals for whom cultural notions of cooperation and sharing expressed in terms of the proper behavior of close kin to one another are not applicable due to their system of cousin marriage. In effect, the sealing partner solution had group-level benefits for which individuals had access only if individual interests sufficiently were suppressed so as to ensure that individual interests did not override group interests. The sealing-partner solution, to put it in terms of group versus individual selection, was an example of group selection, but was an instance of group selection for which the payoff was the ability to survive along the Arctic Coast, thereby gaining access to resources that were not accessible to other groups living inland and further to the south, such as the Athabaskan Indians. Settlement of the American continent, beginning around 15,000–20,000 BP, excluded the Arctic Coast until relatively recently, most likely due to the difficulty in formulating a feasible means for surviving the Arctic winter. While settlement of the Alaskan Coast began much earlier, settlement of the Arctic Coast eastward to Greenland by the Inuit did not occur until around the 13th century, and intersected with the Norse settlements along the southwestern coast of Greenland during that time period.

The Netsilik cultural and material systems, whether robust or resilient, depended heavily upon the monitoring of current conditions and making adjustments according to that monitoring. Decisions on whether or not to keep a female offspring were based on a family's assessment of its ability to maintain an adequate supply of food resources with an additional consumer in the family. Monitoring of the family's current and expected future state enable the Netsilik, in this instance, to make the family's food procurement robust in the face of a "shock" in the form of a new food consumer through either incorporating the new food consumer if feasible, or through removal of the "shock" so that the family, viewed as a food procurement system, could return to equilibrium. Similarly, parents arranged marriages for marriageable offspring based on the assessment by the respective families of the benefits that would accrue from the proposed marriage. And the system of sealing partners was probably the most complicated of

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these three systems, as it interfaced with a number of aspects of Netsilik life. At one level, it had to do with access to seals during the winter (a material utility); at another level, it had to do with the problem faced by all societies, namely, how to construct social groups in which individual interests must be submerged for the benefit of group cohesiveness (a cultural utility). The latter involves monitoring based on assessment and reassessment of relations between and among individuals and between and among families, and never seems to reach a stable equilibrium.

Social relations are, perhaps, the most complex aspect of human societies, as each of the parties involved may have different and not necessarily compatible goals, making it difficult, if not impossible, to find a configuration of interpersonal relations that is stable through time. In contrast to optimal or near-optimal solutions that are found in the material domain—hence, solutions that do not require constant monitoring—the social dimension expressed through relations that are defined culturally is subject to multiple interpretations by the parties involved, thereby making it difficult to arrive at any single, coherent pattern of interaction satisfactory to all parties. What appears to be unusual about human societies is their attempt to construct a difficult balance between, on the one hand, systems that are robust or resilient and, on the other hand, systems that can incorporate a high degree of individuality. The latter aids a search for an optimal solution in the material domain, as it increases the effectiveness of sampling the material domain when individuals try out novel configurations of conditions, but this also makes it difficult to arrive at a stable configuration in the social domain; hence, either resilience or robustness is achieved only through repeated monitoring of social relations and by using culturally constructed means as a way to simplify the complexity of social relations built around a high degree of individuality. By acting in accordance with a social identity that is understood by other members of one society, interactions are simplified because the parties involved share a common understanding of proper behavior for that social identity. For example, we construct group interaction by also constructing roles that are understood by all members of the group. In a classroom context, the primary roles are student and teacher, and each role entails kinds of behavior that can be expected from the role player, regardless of the particular individual involved. Students in United States schools understand that their role is to sit quietly at desks, pay attention to the teacher, to raise their hand when they want

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to speak, to speak only when recognized by the teacher, and so on. Similarly, the teacher plays the "teacher role" and interacts with students in accordance with everyone's understanding of what is entailed by the "teacher role" and by the "student role." These are learned roles and are part of one's "culture" and are engaged in almost automatically. The group-level advantages of "role-playing" are evident, and the individual benefits arise from those group-level advantages. This implies that some individuals may not find "role-playing" in their individual interests, but such behavior is usually defined as "deviant," "disruptive," or the like and the nonconforming individual may receive reprimand from other members of the group. To put it another way, the ongoing stability at the group level from which individuals accrue benefits depends upon monitoring behaviors in order to maintain group equilibrium; that is, monitoring is needed in this instance to ensure the robustness of the system of interaction.

CONCLUSION

A distinction can be made between robustness and resilience of a system through the way the system responds to transient impulses. Whether there is a gradient from robustness to resilience, or whether there is a "qualitative" difference between resilient and robust systems, is an empirical question. While relatively simple systems (that is, systems without numerous subsystems) have been considered here, it is clear that the distinction can be extended to higher-level systems composed of numerous subsystems. Ecological systems often are considered to be resilient, and in terms of the definitions provided here, this makes sense. The state of an ecological system can be changed substantially by a transient force (such as a wildfire), yet the system as a whole may recover even though individual subsystems have collapsed. Like the palm tree, the ecological system can be shifted to a state substantially removed from its prior equilibrium state and is able to recover from the effects of the transient force.

With human systems, a different kind of system is introduced due to the ability of humans not only to react and respond to their environment, but to construct abstract/symbolically based "environments"—cultures—that are as real in terms of their affect on behavior as the material environment in which individuals are embedded. While the concepts of robustness and resilience also are applicable to systems involving these cultural environments, system monitoring appears to take on a much

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greater significance, especially in the social domain, as equilibrium points (if any) may be at the level of group behavior rather than at the level of individual behavior. To the extent that individuals act in accordance with individual interests, group-level equilibrium will not be maintained without the monitoring of the state of the system and accordingly modifying behavior.

The Netsilik Inuit provide a good example of the complexities that arise with human systems. On the one hand, extreme environmental conditions constrain the range of possible activities consistent with surviving Arctic winters and the time sequence and range of resources that must be exploited during a yearly cycle. In terms of material conditions, Netsilik hunting and foraging is optimal or near optimal given the means of food procurement available to them. In a word, they were well-adapted to the Arctic conditions under which they survived. On the other hand, their adaptive behavior depended upon constructing the cultural conditions under which it could occur, beginning with a cultural means for legitimizing female infanticide. But behavior adaptive in one area could also be "maladaptive" in other areas. Female infanticide led to a shortage of females, hence, to potential conflict by families over who had social control over the groom as a food provider. Their cultural solution was to emphasize cousin marriage, thereby creating yet another problem, namely limited kin networks. That problem was resolved through a system of sealing partners that also removed uncertainty from the distribution of a seal killed by a hunter.

Whereas the behaviors arising from material conditions were stable (i.e., fishing for salmon in the summer, hunting caribou in the fall and playing an odds game against seals in the winter), behaviors relating to the ideational domain were far less stable and required repeated and frequent monitoring by individuals in terms of their position vis-à-vis other individuals. The Netsilik were engaged in an ongoing, changing system of individual and group relations that depended upon repeated monitoring for maintaining equilibrium. Cultural models need to be monitored through interaction of individuals to keep coherency at the group level. Interaction leads people to do what is required to make a cultural model work in the real world, including behaviors one might not otherwise personally engage in. Group-level behavior that arises through individuals attempting to instantiate shared cultural models—in a manner that is individually deducible—provides group-level benefits to individuals. This is true both of systems that are robust and of systems that are resilient.

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